RAWS 1992 Progress Report

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1.0 RAWS Program Review

The RAdar Wind Sounder (RAWS) concept is being studied at the University of Kansas. A dissertation by W. Xin was submitted to MSFC earlier, documenting the RAWS concept and early studies. The radar sensitivity study was then continued by T. Propp and later continued by M. Stuart. Stuart's thesis is scheduled for completion in November, 1992.

The purpose of the RAWS instrument is to measure winds aloft in clouds while providing additional capabilities as an ocean surface-wind and rainfall sensor. The concept of RAWS stems from the Laser Atmospheric Wind Sounder (LAWS) planned to monitor winds via Doppler shifts of lidar return from aerosols in a cloud-free environment. If, however, dense clouds are present, LAWS will be unable to measure the winds below the cloud tops. Thus an instrument that can penetrate clouds is necessary and is the basis for RAWS.

The primary tasks related to the RAWS study are to determine:

1. scattering and attenuation models,
2. required radar sensitivity,
3. optimal frequencies,
4. needed antenna size,
5. suitable scan pattern,
6. removal of the ambiguity imposed by range and Doppler-frequency sizes,
7. spectrum measurements,
8. system configuration,
9. performance as a rain sensor,
10. performance as an ocean-surface wind sensor.

The topics studied at the University of Kansas so far are discussed in the next two sections.

2.0 RAWS Background

Xin studied most items concerning the winds-aloft part of the RAWS program and developed a candidate system after preliminary study of frequencies and sensitivities. The following is a brief summary of Xin's work.

The Xin dissertation concentrated on an initial feasibility study and solution of the more difficult technical challenges for RAWS. For this reason, only three cloud models were used. He used no rain models, and no combination rain-cloud models. Xin analyzed two frequencies that allowed for higher sensitivity for clouds (35 GHz) and more penetration for rain (10 GHz). The peak power (3 KW) was selected to be on the order of that used in current and planned space-borne SARs. The antenna size (8-m diameter) selected is large enough to allow reasonable vertical resolution in clouds and rain along with adequate resolution of individual cells. An orbit height (830 km) was chosen that would give a reasonable coverage swath. Xin also studied a number of waveforms and estimators to eliminate the range and Doppler ambiguities while providing an accurate first moment (mean frequency) estimate. Xin concluded that a covariance estimator with a special modulated pulse-pair waveform produced the least error. The modulation required the first pulse of the pulse-pair to be up-chirped while the second pulse was down-chirped. The chirp modulation allowed the receiver to distinguish between the two pulses permitting the pulse-pair to remain unambiguous in range provided the inter-pair spacing was large enough. Xin then developed a candidate system that summarized all the parameters used in his analysis.

Propp continued the RAWS study by conducting a detailed study of the radar sensitivity issue. He began by searching for an accurate cloud drop-size distribution model to be used in the radar sensitivity calculations. From this literature search, the Deirmendjian distribution model was chosen and used in a system signal-to-noise ratio (SNR) computer program. The Deirmendjian model was then used by Stuart to finalize the radar sensitivity study.

3.0 Recent Accomplishments

In the past year, Stuart verified the Deirmendjian model with data taken from available sources, completed the sensitivity study, and determined the optimal transmit frequency(s).

The Deirmendjian model supports a number of cloud types, each having one or more horizontal layer(s). It specifies the composition (water, ice, or rain), mass density, mode radius, two shape parameters, and altitude limits. The ability to model many different cloud types at various altitudes is a major advantage of the Deirmendjian model. Very little experimental data are available to verify drop-size distribution and reflectivity factor models. However, Gossard published four such data sets from the works of Weickmann-aufm Kampe, Squires, Diem, and Breed [Gossard, 1983]. From a comparison of the Deirmendjian model with the data, good agreement is found for the thinner clouds (median diameter, $D_0 < 100$ µm). Since the data are limited to only the thinner clouds, the large-droplet clouds were not verified. However, this is not of much concern, since in the Rayleigh region the extinction coefficient is proportional to D^3, while the backscatter coefficient is proportional to D^6. This implies the backscatter cross section becomes larger relative to the extinction cross section as the droplet radii increase, and the SNR increases. Thus the system sensitivity is limited by the small-droplet clouds. The large-droplet clouds will present an increase in water content that can be used as a limitation on the radar's sensitivity to rain beneath such clouds. Both rain and ice clouds will provide ample SNR due to their larger droplet/particle diameters.

Figure 3.1 shows a fair-weather cumulus cloud and illustrates the layers generated by the Deirmendjian model. The higher frequencies appear to produce sufficient SNR throughout the entire cloud.

To choose an optimal frequency, some form of presentation was required to compare all cloud types for each frequency. To this end, each cloud layer at each frequency was threshold detected, and the results displayed in a table format. SNR thresholds of 5 and 20 dB were used to create Tables 3.1, and 3.2. These tables show for which frequency a cloud layer exceeds the threshold (indicated by an "X"), crosses the threshold (indicated by a "P"), or is below the threshold (indicated by a "-"). The cloud identification codes in the left column of these tables are followed by letters within parenthesis indicating the cloud layer composition: "i" for ice layer, "w" for water layer, and "r" for rain layer.

As can be seen in these tables, the SNR from the rain layers is sufficient for the lower frequencies even with the 20-dB threshold, with the exception of the light rain (drizzle) of model 21-1. The assumption of ample SNR for ice clouds is realized in that these clouds produce sufficient SNR even with the 20-dB threshold at 94 or 35 GHz. The statement that the thinner clouds set the lower limit on the system SNR sensitivity can also be seen in these tables. The large-droplet clouds (25-2, 25-3, 25-4 and 26-1) in most cases even exceed the 20-dB SNR threshold, indicating they are not significant to the determination of the lower SNR limit. The clouds most instrumental in determining the minimum SNR are the Altocumulus (10-1 and 14-1) and the Low-Lying Stratus (20-1 and 20-2). Due to their minimal water content (0.15 and 0.25 gm^{-3}), these clouds exhibit the smallest values of reflectivity factor (as low as -18.5 dBZ). Only the 94-GHz frequency achieves SNR > 10 dB for these clouds. This implies the 94-GHz frequency is required to provide adequate SNR for the thinnest clouds. If only one frequency is utilized, 24 GHz gives the best overall performance. However, the use of 17 GHz gives a better return from rain in highly attenuating clouds such as the Cumulonimbus (26-1). The combination of either 94 and 24 GHz or 94 and 17 GHz provides the best overall performance.

A preliminary study of the antenna scan pattern is currently being conducted by Stuart and will be documented in his thesis.

4.0 Future Studies

Many topics still require detail study. These topics include:

1. study of estimation of wind velocity from multiple looks,
2. detailed surface-tracking methods,
3. study of RAWS as an ocean surface-wind scatterometer,
4. study of RAWS as a rain measurement sensor,
5. synergism study of LAWS and RAWS,
6. hardware availability.

Figure 3.1 - SNR for fair weather cumulus Deirmendjian cloud model (25-1)

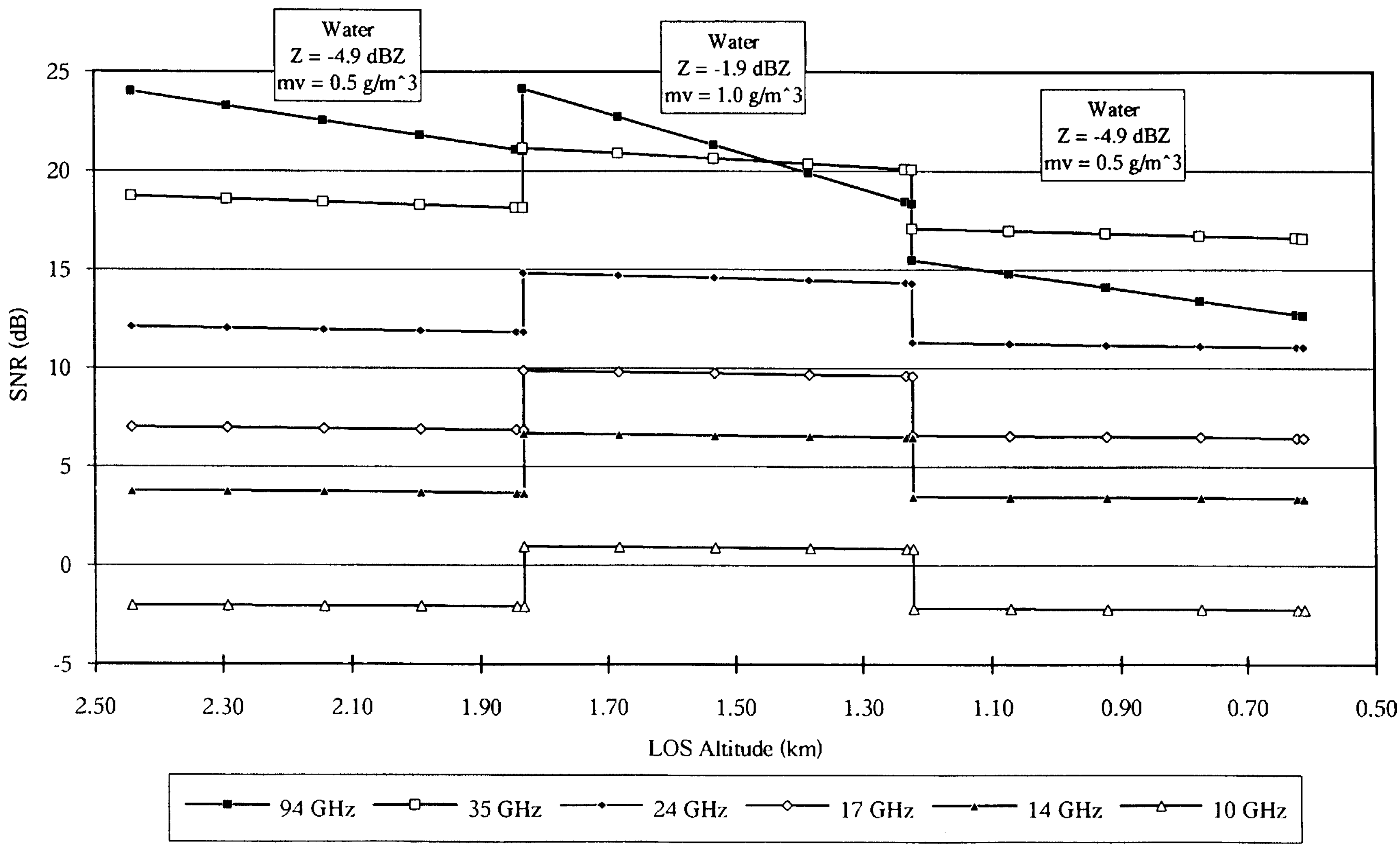

Table 3.1 - Results of 20 dB SNR threshold test for Deirmendjian model.

Cloud	Cloud Name	94 GHz	35 GHz	24 GHz	17 GHz	14 GHz	10 GHz
1-A-1(i)	Cirrostratus	X	X	-	-	-	-
1-M-1(i)	Cirrostratus	X	X	-	-	-	-
1-T-1(i)	Cirrostratus	X	X	-	-	-	-
10-1(w)	Altocumulus	-	-	-	-	-	-
14-1(w)	Altocumulus	-	-	-	-	-	-
20-1(w)	Low-Lying Stratus	-	-	-	-	-	-
20-2(w)	Low-Lying Stratus	-	-	-	-	-	-
21-1C(w)	Drizzle, 0.2 mm/hr	X	X	-	-	-	-
21-1B(w)		P	X	-	-	-	-
21-1A(r)		-	X	X	-	-	-
21-2D(w)	Steady Rain, 3 mm/hr	X	X	-	-	-	-
21-2C(w)		P	X	-	-	-	-
21-2B(w)		-	-	-	-	-	-
21-2A(r)		X	X	X	X	X	X
21-3D(w)	Steady Rain, 15 mm/hr	P	P	-	-	-	-
21-3C(w)		-	-	-	-	-	-
21-3B(w)		-	-	-	-	-	-
21-3A(r)		-	X	X	X	X	X
22-1(w)	Stratocumulus	X	-	-	-	-	-
22-2(w)	Stratocumulus	P	-	-	-	-	-
25-1C(w)	Fair Weather Cumulus	X	-	-	-	-	-
25-1B(w)		P	X	-	-	-	-
25-1A(w)		-	-	-	-	-	-
25-2C(w)	Cumulus, 2.4 mm/hr	P	X	X	X	X	X
25-2B(w)		-	X	X	X	X	X
25-2A(r)		-	X	X	X	X	X
25-3C(w)	Cumulus, 12 mm/hr	P	P	X	X	X	X
25-3B(w)		-	P	X	X	X	X
25-3A(r)		-	-	X	X	X	X
25-4E(w)	Cumulus Congestus	X	X	X	X	X	X
25-4D(w)		X	X	X	X	X	X
25-4C(w)		X	X	X	X	X	X
25-4B(w)		-	X	X	-	-	-
25-4A(w)		-	-	-	-	-	-
26-1F(i)	Cumulonimbus, 150 mm/hr	X	X	-	-	-	-
26-1E(w)		P	X	X	X	X	X
26-1D(w)		-	P	P	X	X	X
26-1C(w)		-	-	-	P	P	X
26-1B(w)		-	-	-	-	X	X
26-1A(r)		-	-	-	X	X	X

Table 3.2 - Results of 5 dB SNR threshold test for Deirmendjian model.

Cloud	Cloud Name	94 GHz	35 GHz	24 GHz	17 GHz	14 GHz	10 GHz
1-A-1(i)	Cirrostratus	X	X	X	X	X	-
1-M-1(i)	Cirrostratus	X	X	X	X	X	-
1-T-1(i)	Cirrostratus	X	X	X	X	X	-
10-1(w)	Altocumulus	X	X	X	-	-	-
14-1(w)	Altocumulus	X	P	-	-	-	-
20-1(w)	Low-Lying Stratus	X	X	-	-	-	-
20-2(w)	Low-Lying Stratus	X	X	-	-	-	-
21-1C(w)	Drizzle, 0.2 mm/hr	X	X	X	X	X	-
21-1B(w)		X	X	X	X	X	-
21-1A(r)		X	X	X	X	X	X
21-2D(w)	Steady Rain, 3 mm/hr	X	X	X	X	X	-
21-2C(w)		X	X	X	X	X	-
21-2B(w)		X	X	X	X	X	-
21-2A(r)		X	X	X	X	X	X
21-3D(w)	Steady Rain, 15 mm/hr	P	X	X	X	X	-
21-3C(w)		-	X	X	X	X	-
21-3B(w)		-	P	X	X	X	-
21-3A(r)		-	X	X	X	X	X
22-1(w)	Stratocumulus	X	X	X	-	-	-
22-2(w)	Stratocumulus	X	X	X	-	-	-
25-1C(w)	Fair Weather Cumulus	X	X	X	X	-	-
25-1B(w)		X	X	X	X	X	-
25-1A(w)		X	X	X	X	-	-
25-2C(w)	Cumulus, 2.4 mm/hr	P	X	X	X	X	X
25-2B(w)		-	X	X	X	X	X
25-2A(r)		-	X	X	X	X	X
25-3C(w)	Cumulus, 12 mm/hr	P	X	X	X	X	X
25-3B(w)		-	X	X	X	X	X
25-3A(r)		-	X	X	X	X	X
25-4E(w)	Cumulus Congestus	X	X	X	X	X	X
25-4D(w)		X	X	X	X	X	X
25-4C(w)		X	X	X	X	X	X
25-4B(w)		X	X	X	X	X	X
25-4A(w)		-	X	X	-	-	-
26-1F(i)	Cumulonimbus, 150 mm/hr	X	X	X	X	X	X
26-1E(w)		P	X	X	X	X	X
26-1D(w)		-	P	X	X	X	X
26-1C(w)		-	-	P	X	X	X
26-1B(w)		-	-	-	X	X	X
26-1A(r)		-	-	-	X	X	X